Low-Carbon Restaurant: Refrigerators Energy Efficiency Aspect

Zih-Ping Ho

Information Center, National Taiwan Normal University

Taipei City, Taiwan

zpho@ntnu.edu.tw

***Abstract*- Global warming poses a grave threat to the world's ecological system. Economic development has led to a huge increase in energy demand, so energy efficiency and saving has become a key issue for most countries and low carbon restaurant pursuit has become a movement. This research constructed a Mixed Integer Linear Programming (MILP) model for maximizing the restaurant refrigerators energy efficiency and reducing the energy lost. The study proposed a Genetic Algorithm hybrid with Tabu Search (GAWT) to solve the model from validation of the proposed approach, a global optimal solution in a small problem size, and compared proposed approach to other famous heuristics, such as Tabu Search and Ransom Search. It was found that storage time of food cargoes in restaurant refrigerators would save 28% when compared to random allocation. In historical literatures, the MILP model did not build and thus an efficient sequence and right take away time cannot be obtained. Future research suggests expanding this research to include more discussion in some extended sub problems is mixed.**

Keywords*- *Restaurant Refrigerators Energy Efficiency; Mixed Integer Linear Programming Model; Genatic Alrorithm; Tabu Search; Carbon Elimination

I. INTRODUCTION

Global warming poses a grave threat to the world's ecological system. Economic development has led to a huge increase in energy demand [1], and therefore energy efficiency [2] and saving [3] has become a key issue for most countries. The United Nations have enacted legislation and designed mechanisms to curb the total amount of carbon emissions, and named this as the Kyoto Protocol.

Automatic control system is a trend [4]. An intelligent refrigerator (or so called *i*-refrigerator) is designed for energy saving. Nowadays, many refrigerators automatically records temperature variations. The temperature variations represented energy efficiency, energy saving, and possible growth of harmful micro-organisms. Besides, an *i*-refrigerator would inform the manager to purchase food and beverage if it occurs inventory shortage. The energy consumption was increased by 10% through frequent door opening [5]. On the other hand, temperature vibrations would affect oil materials quality, such as soybean oil [6]. However, this study does not discuss the energy efficiency of household refrigerators, and instead are the restaurant refrigerators.

Refrigerator energy inefficiency was caused by many reasons, such as food stored for too long [7,8], food layout in a refrigerator [9], open and close the refrigerator door [5], freezing to refrigeration in advance [10,11], Just-in-Time local delivery and inventory problem (lower inventory in refrigerators), and freezing the rest of the food problem.

Based on historical literatures, there were too many refrigerator energy efficiency sub problems, especially hybrid or mixed sub problems. The basic numeric experiments of these mixed sub problems models have to be set up; and offer foundation of the comparative data in future studies. Thus, this study gives the following research assumptions: (1) to ignore the food 3D layout in a refrigerator; (2) to ignore freezing to refrigeration in advance; (3) to ignore freezing the rest of the food problem; (4) food cargo order cannot be separated (each batch of food cargo order only severed for batch customers); (5) safety stock are necessary. Furthermore, the main purpose of this research is to construct a mathematical model for maximizing the restaurant refrigerators energy efficiency through moving food cargoes out of the refrigerators sequence to reduce the energy lost. The rest of the paper is organized as follows. In Section Ⅱ, the literature review is presented. Section Ⅲ describes the problem formulation. The computer results and discussion is in Section Ⅳ. Section Ⅴ concludes the paper and gives suggestions.

II. LITERATURE REVIEW

A. Refrigerators Energy Efficiency Related Literature

Although refrigerators energy efficiency was discussed many times, previous literatures almost always focused on a refrigerator's physical or biological applications discussion. For example, Fukuyo et al. [9] developed a new air-supply system for improving the thermal uniformity and the cooling rate inside a fresh food cabinet of a household refrigerator. In their research, the food layout in a refrigerator affected heat transfer. They achieved a four times higher cooling rate with the new system than that with the conventional ones. Nowadays, cooks are busy cooking; they do not have leisure time to layout or rearrange food into a refrigerator. Thus, when and what sequence to assign food into a refrigerator is an important issue.

Liu et al. [5] stated that six samples of refrigerator/freezer without door opening had less energy consumption than that with door opening by 9.0 – 26.6% at an ambient temperature of 30 ℃ and relative humidity of 70% by testing standards of Japan. Refrigerators under full of food condition had shown higher energy consumption by 10.5% to 14%. In their experiments, energy consumption was increased 10% by frequent door opening.

Bansal et al. [12] proposed an overview of options and potential barriers and risks for reducing the energy consumption, peak demand, and emissions for seven key energy consuming residential products (refrigerator-freezers, dishwashers, clothes washers, clothes dryers, electric ovens, gas ovens and microwave ovens) was presented. Their paper concentrated on the potential energy savings from the use of

advanced technologies in appliances for the U.S. market. They concluded that energy consuming residential products should be minimized due to cost saving.

Negrao et al. [13] stated that household refrigeration systems focused on both energy savings and cost reduction. A trade-off relation between the minimum cost and the minimum energy consumption was achieved and studied.

B. *Restaurant Related Literature*

Most restaurant related literatures did not directly discuss restaurant refrigerators. In 2000, Ho and Wang [14] discussed dishes sequencing in a culinary room, and the dishes would be regarded as orders in a factory. Kure et al. [15] published the great assistance of a back-office layout in the food and beverage industry toward the implementation of a HACCP system. In their paper, a food safety aspect was offered, however, it focused on the principle of HACCP; energy efficiency was not discussed. Kure et al. [16], Ho and Lo [17] also focused on food safety; energy efficiency was ignored. Ho [18] discussed a dynamic orders selection problem to maximize restaurant profits. Ho and Lee [19] first built a carbon footprint mathematic cost model for a culinary room facilities layout problem. Ho [20] furthermore discussed restaurant facilities layout problem with a reducing carbon footprint aspect.

Although numerous literatures were related to discuss restaurant production management, there is only a limited amount of literature available on reducing carbon footprints in a restaurant, especially in a restaurant refrigerators energy efficiency aspect.

III. PROBLEM FORMULATION

This research adapts a MILP (mixed integer linear programming) cost model to minimize storage time of food cargoes in restaurant refrigerators. Let *i*, *j* denote food cargo number, $i \neq j$. Let n denote number of food cargoes. Let u_i denote cooking time of food cargoes *i*. Let m_i denote consume time when moving food cargoes *i* out of the refrigerator. Let Pq denote penalty of decreasing of food quality. Let Pe denote penalty of refrigerator energy inefficiency for each cargo. Let *M* denote a big number. Let a_i denote decision variable, which represents take away time of food cargoes *i* out of the refrigerator. Let x_{ij} denote a binary decision variable, if cargo *i* is assigned before *j* in a sequence, then equal to 1; otherwise equal to 0. It shows as follows:

i, *j*: food cargo number, $i \neq j$

n : number of food cargoes

u_i : cooking time of food cargoes *i*

m_i : consume time when moving food cargoes *i* out of the refrigerator

Pq : penalty of decreasing of food quality

Pe : penalty of refrigerator energy inefficiency for each cargo

M: a big number

Decision variables:

a_i : take away time of food cargoes *i* out of the refrigerator

$$x_{ij} = \begin{cases} 1, & \text{if } i \text{ is assigned before } j \text{ in a sequence} \\ 0, & \textit{otherwise} \end{cases}$$

The MILP cost model to minimize storage time of food cargoes in restaurant refrigerators is as follows:

$$\text{Min} \quad TC = \sum_{i=1}^{n} (Pq(u_i - a_i) + Pe(a_i - u_i)) \tag{1}$$

$$a_j - a_i + \mathrm{M} \cdot (1 - x_{ij}) \geq m_i \tag{2}$$

$$a_i - a_j + \mathrm{M} \cdot x_{ij} \geq m_j \tag{3}$$

$$x_{ij} \in \{0,1\} \tag{4}$$

The Objective (1) is to find a minimal cost to minimize storage time of food cargoes in restaurant refrigerators. In Eq. (2) (3), these are *sequence* constraints; it represents a cook takes food cargoes for cooking in turn. Eq. (4) declares artificial *binary decision variable* constraints.

IV. COMPUTER RESULTS AND DISCUSSION

In this section, the results of a series of computational experiments were conducted to test the effectiveness of the proposed approach. The proposed approach was genetic algorithm with Tabu Search (GAWT or GA instead), coded in Visual Basic computer language and all tests were conducted on a personal computer with Celeron (R) Dual-Core CPU at 2.10GHz and 1GB of RAM memory. The Random hybrid Tabu Search (RHT or general called TS) and Random Search (RS) were also coded in Visual Basic computer language. The Random Search is similar to human experience; it would be made in a few seconds, but random (or guess). Tabu search is a famous heuristics. It always puts emphasis on finding a new path; it books a path if it already passed through. Genetic algorithm is the foundation of artificial intelligence methodology. In this study, GA hybrid TS; if the path already passed through, on the next occasion, GA will not repeat it again.

The exact solution in a small problem size was using Lp_solve5.5 (for command line mode, it was also an executable file) software. The software is an open source code (C++) complier program; it was established by global academic institutes and mathematical societies. The Lp_solve5.5 can solve the problem size with n = 11, it contains sixty-six decision variables and 110 constraints; besides, it generated global optimal solution due to the proposed model being built in MILP form. The artificial binary variable would form a NP-hard problem because the problem has to process at least a 2^m brand-and-bound search for obtaining an integer solution [21]. Therefore, in order to avoid the trials of factorial possibilities, this research should propose heuristics to solve the optimization problem. In the real industrial environment, the global optimization tools cannot output the solution when problem sizes are too large (due to there being too many variables and constraints), even running in a super computer, it still cannot find a feasible solution in a reasonable time without heuristics.

Since the proposed model is a new problem, no published solution method is available for comparison. Thus, this research conducted an experimental design, by the problem size n = (20, 50, 75), for comparing the performance of heuristics. The parameters of *GAWT* were listed in Table I. The parameters of *RHT* were listed in Table II.

TABLE I SET OF PARAMETERS FOR *GAWT*

Parameter	Value
Cross Over Rate	0.75
Mutation Rate	0.05
Generations	100
Populations of Gene Pool	10
Tabu	1.00
Termination Time (sec)	300

TABLE II SET OF PARAMETERS FOR *RHT*

Parameter	Value
Repeat Times	100
Tabu	1.00
Termination Time (sec)	300

The comparisons of *GAWT*, *RHT*, *RS*, and global optimal solution results in small problem sizes were shown in Figure 1, and its computation time (CT) is shown in Figure 2.

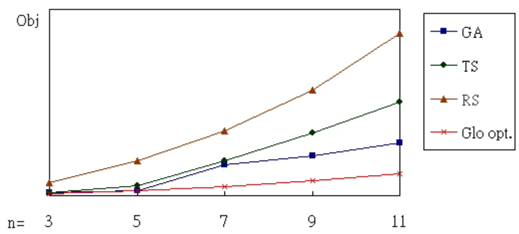

Fig. 1 Comparison results of objective values in small problem sizes

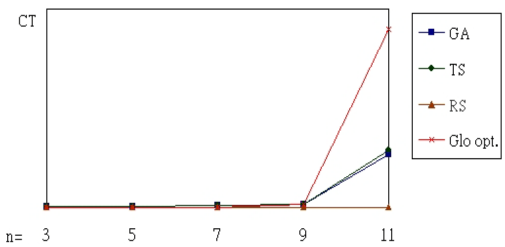

Fig. 2 Comparison results of computation time in small problem sizes

We found Lp_solve generated global optimal solution in a small problem size. The *GAWT* and *RHT* belonged to linear increasing when comparing to global optimal solution. The *RHT* outperformed *RS* (in the real world, decision is similar to *RS*). The *GAWT* outperformed *RHT*, it represented evolution computation had more efficiency. However, when n = 11, Lp_solve consumed more CT due to factorial possibilities trials, and it cannot find a solution within 24 hrs when n = 12. The heuristics of *GAWT*, *RHT*, and *RS* would find an acceptable solution in a reasonable time in this study.

In a large problem size, n = (20, 50, 75), the results are listed in Table III, and shown in Figures 3 and 4.

TABLE III THE COMPARISON RESULTS OF HEURISTICS

Problem (n)	Best Solution (Objective Value) Obtained		
	GAWT	***RHT***	***RS***
25	2087	2428	3089
50	8904	9442	12480
75	21411	22387	27921

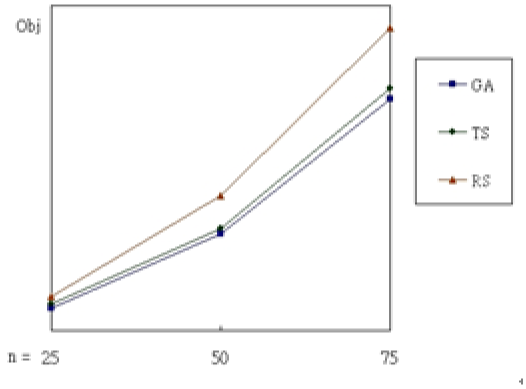

Fig. 3 Comparison results of objective values in large problem sizes

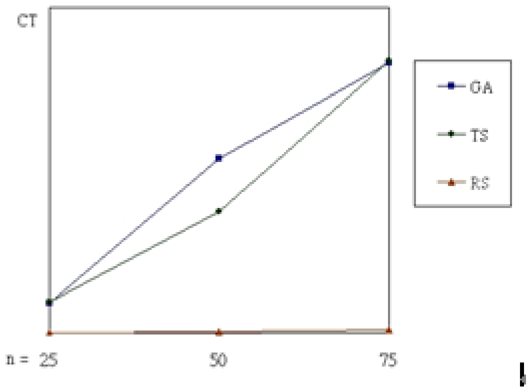

Fig. 4 Comparison results of computation time in large problem sizes

The heuristics of *GAWT*, *RHT*, and *RS* also would find an acceptable solution in reasonable time in this study with a large problem size. The best solution (objective value) is obtained by *GAWT*, followed by *RHT*. The *RS* generated the worst solution (objective value). Furthermore, in Table III, we found that *GAWT* outperformed *RS* by an average of 28%. It represented that storage time of food cargoes in restaurant refrigerators would save 28%, and a refrigerators energy efficiency has more effects if we carefully considered moving food cargoes out of the refrigerators by an efficient sequence and right take away time. Although it is similar to Liu et al. [5], refrigerator/freezer without door opening had less energy consumption than that with door opening frequently by 9.0-26.6%; however, in their research, the mathematic (MILP) model did not build and thus an efficient sequence and right take away time cannot be obtained.

V. CONCLUSION AND SUGGESTION

Global warming poses a grave threat to the world's ecological system. Economic development has led to a huge increase in energy demand, and therefore energy efficiency and saving has become a key issue for most countries, and low carbon restaurant pursuit becomes a movement. This research constructed a mathematical model for maximizing the

restaurant refrigerators energy efficiency and reducing the energy lost. The study proposed *GAWT* to solve the model from validation of the proposed approach to global optimal solution in a small problem size and compared proposed approach to other famous heuristics, such as Tabu Search and Ransom Search. It found storage time of food cargoes in restaurant refrigerators would save 28% when compared to random allocation. In historical literatures, the mathematic (MILP) model did not build and thus an efficient sequence and right take away time cannot be obtained.

However, it may result in different costs if some assumptions are revised. Future research suggests expanding this research to more discussion in some mixed extended sub problems.

REFERENCES

[1] G. Dwivedi, S. Jain, and M. P. Sharma, “Impact of biodiesel and its blends with diesel and methanol on engine performance,” Int. J. Ene. Sci., vol. 1, No. 2, pp. 105–109 , 2011.

[2] S. Chamoli, A. Patil, and J. S. Saini, “Parametric optimization of solar assisted bioreactor,” Int. J. Ene. Sci., vol. 1, No. 2, pp. 125–130 , 2011.

[3] Z. P. Ho, “Geographical information of dynamic carbon footprints management system in orders and trucks assignment problem,” Adv. Materials Res. J., In Press.

[4] J. Singh, R. Singh, and S. K. Aggarwal, “Design of substation AMR and control system with reconfigurable embedded system,” Int. J. Ene. Sci., vol. 1, No. 2, pp. 62–66 , 2011.

[5] D. Y. Liu, W. R. Chang, and J. Y. Lin, “Performance comparison with effect of door opening on variable and fixed frequency refrigerators and freezers,” App. Thermal Engi., vol. 24, No. 14, pp. 2281–2292 , 2004.

[6] S. Jain and M. P. Sharma, “Modeling and analysis of oxidation and thermal stability of biodiesel,” Int. J. Ene. Sci., vol. 1, No. 2, pp. 93–98 , 2011.

[7] J. K. Kim, E. M. D. Sa, and M. A. Harrison, “Listeria monocytogenes survival in refrigerator dill pickles,” J. Food Protection, vol. 68, No. 11, pp. 2356–2361 , 2005.

[8] S. E. Gilbert, R. Whyte, and G. Bayne, “Survey of internal temperatures of New Zealand domestic refrigerators,” British Food J., vol. 109, No. 4, pp. 323–329 , 2007.

[9] K. Fukuyo, T. Tanaami, and H. Ashida, “Thermal uniformity and rapid cooling inside refrigerators,” Int. J. Refrigeration, vol. 26, No. 2, pp. 249–255 , 2003.

[10] J. Euans, E. Hammond, and A. Gigiel, “Development of a novel multi-capillary , multi-temperature commercial refrigerator cabinet with common low-pressure receiver,” Int. J. Refrigeration -Revue Internationale Du Froid, vol. 31, No. 3, pp. 464–471 , 2008.

[11] K. Azzouz, D. Leducq, and D. Gobin, “Enhancing the performance of household refrigerators with latent heat storage: An experimental investigation,” Int. J. Refrigeration -Revue Internationale Du Froid, vol. 32, No. 7, pp. 1634–1644 , 2009.

[12] P. Bansal, E. Vineyard, and O. Abdelaziz, “Advances in household appliances - A review,” App. Thermal Engi., vol. 31, No. 17-18, pp. 3748–3760 , 2011.

[13] C. O. R. Negrao and C. J. L. Hermes, “Energy and cost savings in household refrigerating appliances: A simulation-based design approach,” App. Energy, vol. 88, No. 9, pp. 3051–3060 , 2011.

[14] Z. P. Ho and C. F. Wang, “A study on application of object-oriented programming techniques to food and beverage preparation scheduling problem,” Food Sci. and Tech. Conference on Republic of China, No. 181, pp. 1–10 , 2000.

[15] Y. Kure and M. J. Jhou, “The great assistance of back-office layout in food and beverage industry toward the implementation of HACCP system,” Quality J. of Taiwan, vol. 46, No. 1, pp. 22–25 , 2010.

[16] Y. Kure and F. L. Yang, “The principles of HACCP in food preparation and their applications,” Quality J. of Taiwan, vol. 46, No. 1, pp. 16–21 , 2010.

[17] Z. P. Ho, “Routes of inventory and warehousing management within culinary facilities - A food safety aspect,” Logistics Mana. Rev., vol. 4, No. 1, pp. 125–134 , 2010.

[18] Z. P. Ho, “An application of new approach for dynamic orders selection to maximize restaurant operational profits,” Adv. Materials Res. J. In press.

[19] Z. P. Ho and H. J. Lee, “Food and beverage delivery process of culinary room–Reducing carbon footprint aspect,” 1st National Food and Beverage Innovation and Culture Development Conference. Republic of China, vol. 1, pp. 1–6, Nov. 26 2010.

[20] Z. P. Ho, “Restaurant facilities layout - Reducing carbon footprint aspect,” App. Mechanics and Materials, vol. 58, No. , pp. 613–628 , 2011.

[21] K. H. Rosen, Discrete mathematics and its applications, 1st ed., McGraw Hill Press.